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AN OPEN-OCEAN V/STOL SEAPLANE FOR THE ASW MISSION WITH EMPHASIS ON TRACKING AND SURVEILLANCE

(Title Unclassified)

by

Robert M. Williams

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RESEARCH AND DEVELOPMENT REPORT

November 1965

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Foreword

This paper is an extension of the work covering operational aspects of the TMB Open-Ocean V/STOL Seaplane Following a program review presented at the Office of Naval Research, several items involving system costs and operational doctrine were deemed worthy of further study. The extension suggested encompassed the following:

1. Hold continuously in contact maintenance one nuclear submarine.
2. Consider an alteration of bearing accuracy.
3. Use single crew on 15-hour mission.
4. Eliminate the need for a tanker aircraft.
5. Consider use of one set of buoys for several aircraft, each with replacement batteries.
6. Consider degradation of acoustical range as a function of sea state.
7. Decrease radius of action as necessary.
8. Consider 48-hour turn-around time.
9. Compare the proposed system with an existing fixed-wing system.

The extended efforts treated from 1 through 7, with the last items left for application by the appropriate experts.

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SUMMARY

The report is an operational analysis of an ASW open-ocean V/STOL seaplane design concept. It encompasses approximately 10,000 hours of computerized passive sonobuoy tracking simulation for a randomly moving 0- to 5-knot submarine. An attempt has been made to evaluate the operational effectiveness of a tracking technique utilizing four Air Transportable Sonar Surveillance System (ATSSS) buoys with bearing errors (accuracy) allowed to vary from $\pm 1^{\circ}$ to $\pm 10^{\circ}$.

The results of the simulation indicate that a maximum bearing error of 5° is acceptable. However, the inclusion of directional Low-Frequency Acoustical Ranging (directional LOFAR) buoys as a complementary system would provide greater reliability and wider applications, and would permit higher bearing errors. The wide range of on-station times possible under different combinations of submarine tactics, sea state, and distance from base is indicative of the seaplane's capability for a variable-length mission. By utilizing inflatable vertical floats, the craft movement is attenuated sufficiently to permit long crew endurance times.

INTRODUCTION

The Office of Naval Research (ONR) outlined (Reference 1) eight ASW tactical tasks applicable to an Air-Sea craft. These included Task Force Screening, Convoy Protection, Fixed Barrier Maintenance, Moving Barriers, Contact Area Investigation, and Tracking and Surveillance. Although the seaplane exhibits a potential in all of these areas, the primary mission under consideration is submarine tracking and surveillance (contact maintenance) for extended periods of time without attacking and, if possible, without revealing the presence of the Air-Sea craft. A typical seaplane mission is to maintain continuous passive contact with a post-1970 nuclear submarine moving on a low-speed random course in a high sea state several hundred miles from the seaplane base.

The seaplane is assumed to arrive on station with one replacement buoy and a fuel supply which varied with the distance from base. The simulation is based on the assumption that the target was already triangulated by three buoys, and that the seaplane had just landed to begin

[redacted]

monitoring. This mission depends upon buoy sharing between subsequent aircraft, but eliminates fueling support. The operational study of the tracking results considered a conventional maximum mission length (similar to that of the P-3A) of 15 hours, based on current single crew endurance. However, it should be noted that this fixed mission length places a severe limit on the seaplane's capabilities and does not consider the probable crew rest time that could be obtained with vertical floats. Reference 2 has indicated that increased system effectiveness derives from extending the 15-hour limit.

The approach followed in designing the V/STOL seaplane was to (a) define the basic contact maintenance mission, (b) design the vehicle for this mission, and then (c) expand the seaplane capabilities into other related ASW areas. The seaplane design study with mission profiles and estimated performance is given in Reference 2. The present report enlarges upon the initial study presented in Reference 2, in the section on Contact Maintenance.

As demonstrated in Reference 2, the accuracy with which the V/STOL seaplane can track a submarine is a function of the bearing error (accuracy) of each buoy and its distance from the target. The allowable distances of the buoys from the target are determined by the probability limits, which, in turn, depend on the detection characteristics. If any buoy detection probability is below a minimum limit, a seaplane maneuver is required to change the buoy triangulation pattern.

The bearing error of an ATSSS buoy is principally a function of the electronics, number of hydrophone arrays, and the referencing system on the deep unit, and therefore it is an important factor in determining buoy cost. As a result of further discussion of the contact maintenance problem within the Office of Air Programs, Naval Applications Group, ONR, this study was initiated to analyze the tradeoff in acceptable bearing error versus target acquisition range (localization error) in order to further define the system effectiveness of a passive buoy design.

APPROACH TO THE PROBLEM

GENERAL CONSIDERATIONS

Because of the system complexity associated with an investigation of this type, it was impossible to include all the variables associated

with a practical application. A sonar system is immensely complex because of the many eccentricities and interreactions, which are quite nebulous in some areas. Therefore, it was necessary to make certain idealized and simplifying assumptions.

Any study of this type must include a definition of all the important variables. Experimental values were used wherever possible in the mathematical model; and where not known, an idealized or an assumed value was used to approximate the expected real effect. A simplified model was built, neglecting relatively minor parameters and combining others into a single variable. By constantly re-evaluating the buoy and aircraft parameters and anticipating irregularities, it was possible to gradually include in the mathematical model one by one most of the pertinent variables. An example of this assertion is the refinement introduced in the probability of detection through a series of trials. Initially, a seaplane maneuver was made if the probability of detection of any buoy fell below 40 percent. A more sophisticated approach was later incorporated, using the concept of cumulative probability limits and an optimized buoy drop location. The result was a significant improvement in tracking capability and a decrease in seaplane fuel consumption.

This approach to the problem gradually converges to a level determined by the degree of sophistication of its principal components. Therefore, it is not meaningful to refine buoy limits to ±5 percent probability if the estimated detection range curve is accurate to only ±25 percent. Similarly, this analysis to determine an acceptable bearing error is only as relevant as the buoy detection curve utilized (Figure 1). Additional comparative and relevant information on predicted performance of an ATSSS buoy may be found in References 3, 4, 5, and 6.

TRACKING STRATEGY

The V/STOL seaplane utilized four ATSSS buoys and always endeavored to keep three buoys in operation tracking the target. The buoy detection range was degraded for submarine speeds from five to zero knots. The detection curve (Figure 1) represents the average effects due to sea noise,

buoy characteristics, depth velocity profiles, and target radiated noise for a transducer at 15,000 feet. The acquisition target was a moderately quiet nuclear submarine estimated to be representative of those of the post-1970 period.

The probability of detecting a maneuvering submarine was optimized for a 3° bearing error (accuracy) to obtain the lowest seaplane fuel consumption. The limits for other bearing errors were then extrapolated from these results in order to estimate maximum performance. Disposable buoys were not used in the model simulation, although the preliminary design weight estimation allowed for the stowage of thirty directional LOFAR buoys (Reference 2). As the submarine performed its random maneuver, the course and position were estimated by computing the intersections of bearing lines from each of the buoys. After each "fix," the estimated probability of detection was computed using the current speed and range information. If these probabilities were below minimum acceptable values, the seaplane maneuvered and dropped another buoy at a location of higher estimated probability, biased according to the current submarine course estimate. The seaplane then flew to the buoy of lowest detection probability and retrieved it for the next placement, as required by the submarine maneuvers.

FACTORS AFFECTING TRACKING PERFORMANCE

Tracking of a submarine is dependent upon the detection probability limits of the buoys and maintenance of a minimum bearing error.

LIMITS FOR DETECTION PROBABILITY -- The following limits were assumed as the minimum acceptable values of probability of detection for a given buoy pattern:

1. A minimum detection probability of 20 percent for an individual buoy.

2. A minimum of 50 percent for the sum of the detection probabilities of any two buoys.

3. A total of at least 120 percent for the sum of the detection probabilities for all three buoys.

In general, setting the minimum probability limits higher provided more accurate submarine position and course estimates, but it also required more seaplane maneuvering (and hence greater fuel consumption).

BEARING ERROR -- Since the computed position of the target is at the intersection of the bearing lines, a large bearing error could have a significant effect on tracking performance. When the bearing lines intersect at angles between 60° and 120°, however, the effect of bearing error was not critical. But, as the target moves along its course and the intersections approach 0° or 180°, even small bearing errors may give rise to prediction of target positions far beyond the actual target position (see Figure 2). This effect is due to the randomness of the indicated bearings within their "error fans." As a result, the maneuver indicated for the seaplane may cause a loss of the target.

In the case of bearing errors, the tradeoff is again the tracking accuracy versus fuel consumption — a smaller bearing error would result in fewer maneuvers.

OPTIMIZATION OF DETECTION PROBABILITY LIMITS -- In order to isolate the effects of bearing error on tracking performance, the buoy detection probability limits were held constant for the entire simulation. However, these limits were first optimized by studying the relative seaplane endurance obtainable against eight different submarine tactics. Four combinations of limits at a bearing error of ±3° were each tested for 1060 hours of simulation with a 0- to 5-knot randomly maneuvering submarine. Although no single combination excelled in all cases, one resulted in better submarine tracking with fewer seaplane maneuvers. Of the three cases which could maintain contact, the maximum variation in fuel consumption was 75 pounds per hour. The optimum combination of limits was then used for the remainder of the investigation with the assumption that these limits could be slightly improved for other bearing errors. It may be noted in Figure 3 that there is a noticeable change of slope for errors greater than ±3°, because of the optimization of the probability limits. In general, to obtain the same tracking performance as obtained at 3°, the limits could be increased at the lower bearing errors and thus fewer maneuvers would be required. At the higher bearing errors the limits should be slightly reduced, because of a higher incidence of intersection

errors and target loss. The dashed curves are an intuitive estimate of the theoretical improvements obtainable if each individual bearing error is optimized.

RESULTS AND DISCUSSION

As described in Reference 2, the computer program for the IBM 7090 generated a series of maneuvers by randomly selecting values from distribution curves of speed, course change, and duration on course. For the bearing error investigation, five representative 0- to 5-knot submarine tactics were used, each one totaling 113.5 hours (Table 1). The important parameters considered in analyzing the tracking performance of these tactics were:

1. The average localization error.
2. The average course estimation error.
3. The average seaplane fuel consumption.

DISCUSSION OF THE PARAMETERS

Average localization error may be thought of as the average target acquisition range which the buoy system was able to maintain. Although it fluctuated greatly from time to time, the important consideration in contact maintenance is the absolute tracking ability; that is, the capability of the seaplane to keep in nearly continuous contact with the submarine. It can be seen in Figure 4 that the localization error is a general index of this capability and that quite often the vehicle was within the necessary range for a Mark 46 torpedo attack. For attack with a larger position error, either ATSSS or LOFAR buoys could be dropped in more advantageous positions, thus affording higher confidence in convergence and kill.

The average course error is interrelated with the average localization error. By use of a "least squares" technique, the computer estimated target course and then used this information in positioning the next buoy in a favorable detection probability location. Incorrect course estimates resulted in less desirable buoy placements with an inherent degradation of position estimates.

The fuel consumption of the seaplane placed an upper limit on the on-station tracking time, varying as a function of submarine tactics and thereby suggesting the possibility of the variable-length mission described later.

As the bearing, detection probability, and course data routines for the computer all used random numbers, the data were never exactly repeatable. Occasionally, a data point fell far from the average, because of the slight probability that the target could be lost even with small bearing errors. These chance occurrences are also indicative of the degree of confidence which may be placed in the computerized model. In the fairing of curves, the validity of such random points has been considered and weighted accordingly. For example, for tactic E a total loss occurred with bearing errors of 2°, 7°, and 9° and a temporary loss occurred at 3°; whereas, at 5°, the target was tracked without difficulty. A reliable decision on the limiting bearing accuracy could be made only after carefully studying the detailed tracking data printout from the computer.

The most severe tracking case occurred when the submarine (target) speed and course fluctuated so frequently that the seaplane had to maneuver constantly. Any further increase of speed distribution (0 to 10 knots) would have made ATSSS tracking with a single aircraft unfeasible. However, the submarine noise generation in this speed range makes an integrated ATSSS — directional LOFAR system look promising.

RESULTS OF THE COMPUTATIONS FOR FIVE SUBMARINE TACTICS

The following paragraphs refer to Figures 3, 4, and 5 and Table 1:

Tactic A -- All the bearing errors tracked without difficulty. Although occasional false intersection maneuvers occurred at 7°, the long zero-knot periods allowed ample time to relocate the buoys. The maximum average localization error approached 1000 yards at 9°.

Tactic B -- No localization error was calculated for this tactic, but no serious difficulty was encountered until the bearing error became 9° or 10° , when total loss of target occurred.

Tactic C -- The higher bearing errors gave difficulty. The seaplane temporarily lost contact with the submarine at bearing errors of 4°, 5°, and 7° because of poor angular intersections. However, the seaplane was able to reestablish contact after initiating a search routine. The average localization error exceeded 1400 yards at 9° and the submarine

course error leveled out at 30°. Although seaplane fuel consumption approached 900 pounds per hour at 10°, contact was maintained.

Tactic D -- The higher bearing errors again experienced difficulty, due to unfavorable angular intersections of the bearing lines. The target became lost for several seaplane maneuvers at 4° and 9°. The maximum average localization error approached 1600 yards at 9°. Tracking becomes very unreliable above 7°.

Tactic E -- This was the limiting case. Target speed fluctuated so frequently that constant maneuvering was required to maintain contact. When a false maneuver occurred, the localization error diverged to such an extent that the search routine was unable to reestablish contact. Three combinations of buoy detection probability limits were attempted at 5°, 7°, and 9°, but in none of the cases was contact maintained. Localization error for 5° was over 1150 yards, although no serious tracking difficulty was encountered. A temporary loss occurred at 3° because of erroneous fix information.

EFFECT OF BEARING ERROR ON OPERATIONAL CAPABILITY

Figure 6 shows the tradeoff permitted in acceptable bearing error versus seaplane on-station maneuver time. The fifteen-hour line represents the maximum allowable time versus range for a conventional mission, which would include 35 minutes ready time to take off, a 277-knot cruise out, and a 283-knot return. The bearing curves represent the maximum tracking time that a given bearing error may allow, assuming a fuel reserve of 1000 pounds. Only those bearing errors which were acceptable for the two most difficult tactics are shown.

All other cases exceeded the 15-hour mission, and against a slow-speed submarine, the seaplane was able to remain on-station over 21 hours at a range of 1000 miles. It may be noted also that, without the fuel reserve, all bearing errors would cross beyond the 1000-mile range.

INTEGRATED ATSSS – LOFAR SYSTEM

Although it was not considered in the computer simulation, the use of a disposable directional LOFAR buoy could result in significant improvements in the seaplane's performance. The light weight and air drop capability

of LOFAR buoys would make them ideal additions to an ATSSS system. Such buoys could be dropped in all cases of uncertainity of target position. For example, the seaplane could make disposable drops on the way to re-position an ATSSS buoy whenever the possibility of intersection errors appeared, thus providing an additional cross bearing. In the case where the search routine was necessitated, the seaplane could easily drop disposable buoys in the suspected area and thus obtain information on the optimum drop location for the longer range ATSSS.

The problem of tracking a random moving 1- to 15-knot target could also be solved by using ATSSS drops complemented by disposables. Each time an ATSSS buoy was situated at a long range for detection of high-speed targets several disposables could be dropped closer to the estimated submarine position. This system would then contain the submarine in two concentric deployment patterns, thus enabling contact to be maintained even if target speed fluctuated severely. If the submarine moved at prolonged high speed (10 to 15 knots), the seaplane could simply remain airborne and drop disposable buoys in a manner similar to that of the P-3A airplane.

The effect of LOFAR drops on bearing error has not been studied, but it is probable that both tracking reliability and bearing error could be significantly improved with their introduction.

VARIABLE-LENGTH MISSION

The flexibility of a variable-length mission appears to be a favorable feature of the V/STOL seaplane's endurance capabilities. For a continuously moving target, the 15-hour mission represents a reasonable crew endurance limit. However, for a submarine which operates predominately in the 0 to 2-knot range for three or more hours at a time, a longer mission should not impose serious crew problems. The inflatable vertical floats should attenuate wave motion sufficiently to allow the crew several hours of rest.

A minimum complement consisting of a pilot-communications officer, a tactical officer, and one additional ANEW crewman could maintain the aircraft and ASW systems. The over-all mission length would then become a function of sea state and submarine tactics with some reasonable upper limit of on-station time.

CONCLUSION

For the passive ATSSS buoy system described, the most difficult tracking case encountered was the continuously moving submarine (0 to 5 knots). A bearing accuracy of $\pm 5^{\circ}$ to $\pm 6^{\circ}$ appears to be sufficient in the majority of these cases, although some random losses will still occur. The endurance capabilities of the V/STOL seaplane were excellent in all but the most extreme combinations of long range and a continuously moving target with wide speed fluctuations.

Two significant improvements in the seaplane's ASW performance are considered feasible by:

1. Introducing an integrated ATSSS – LOFAR system which could provide higher confidence in contact maintenance for the 0 to 5-knot target and could also increase the seaplane's capabilities into the 0 to 15-knot range.

2. Using a variable-length mission to provide greater utilization of surveillance and tracking capabilities over a wide range of possible sea states and submarine tactics.

Aerodynamics Laboratory
David Taylor Model Basin
Washington, D.C.
September 1965

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Table 1

Summary of Submarine Tactics

[0 to 5 Knots]

Tactic	Speed Distribution	Course Variation	Average Duration On Course
A	Predominately high (~ 5-knot) and low speeds; stops average 58.2 percent of total time	Large fluctuations averaging 73°	6 hours
B	Even distribution, 0 to 4 knots; stops average 6.8 percent of total time	Large fluctuations averaging 74°	3.7 hours
C	Biased slightly toward high speeds; stops average 9.3 percent of total time	Large fluctuations averaging 70°	4.5 hours
D	Even distribution 0 to 4 knots only; stops average 3.9 percent of total time	Large fluctuations averaging 71°	3.6 hours
E	Even distribution but with no stops	Large fluctuations averaging 70°	4.0 hours

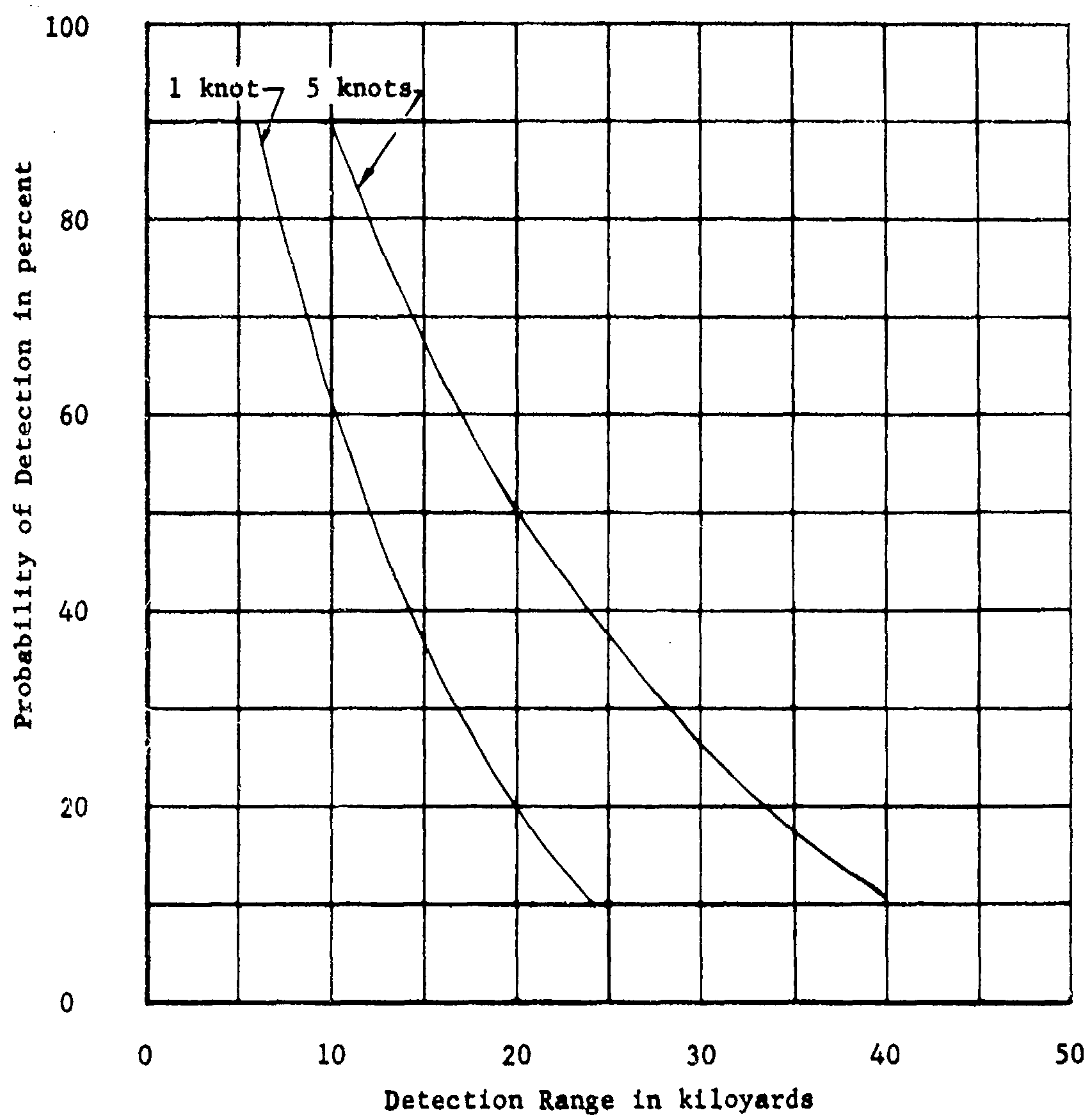

Figure 1 - Estimated Detection Curves With Speed Degradation for ATSSS Buoys

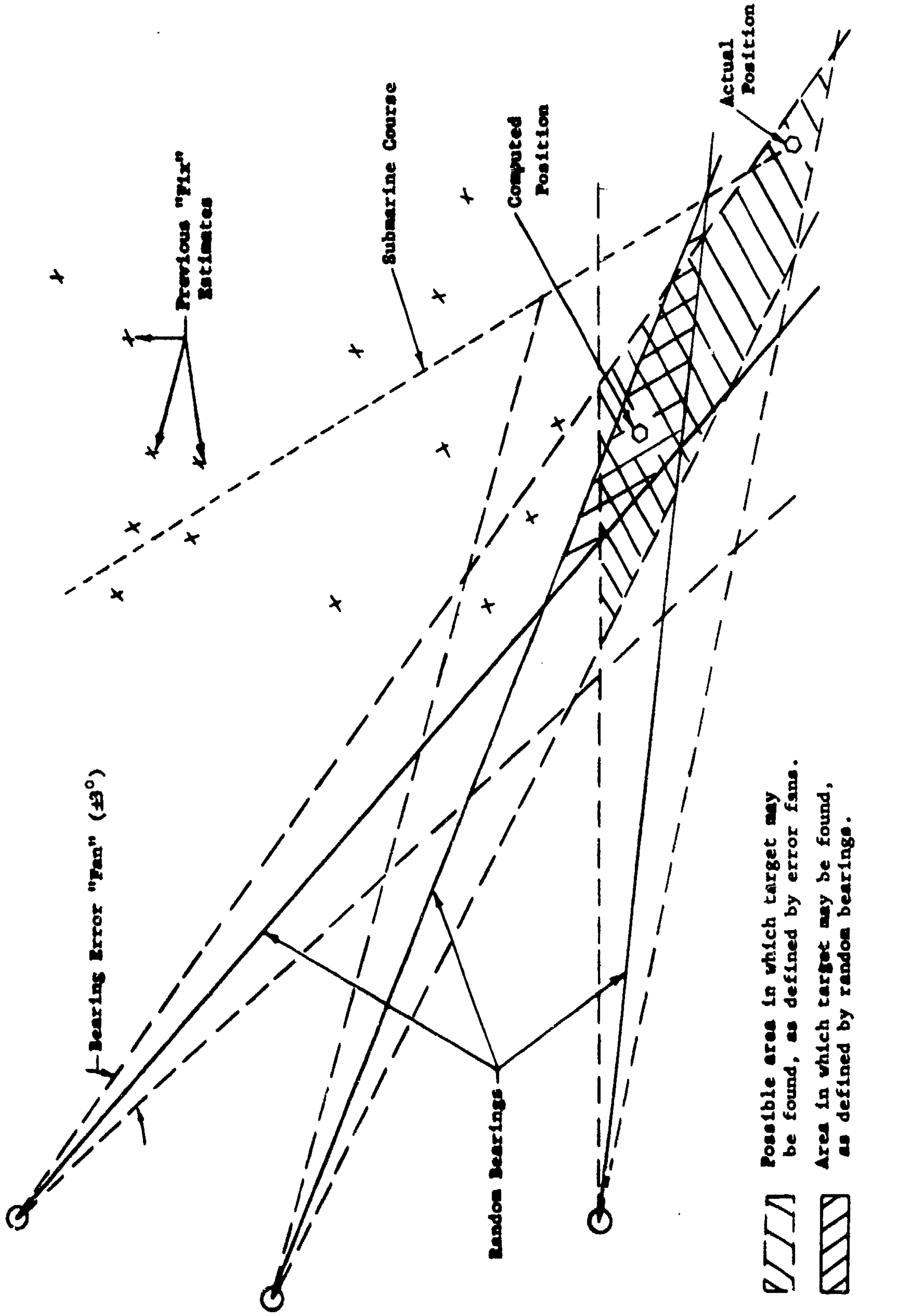

Figure 2 - An Illustration of Intersection Errors Due to Small Angles Between Bearing Lines

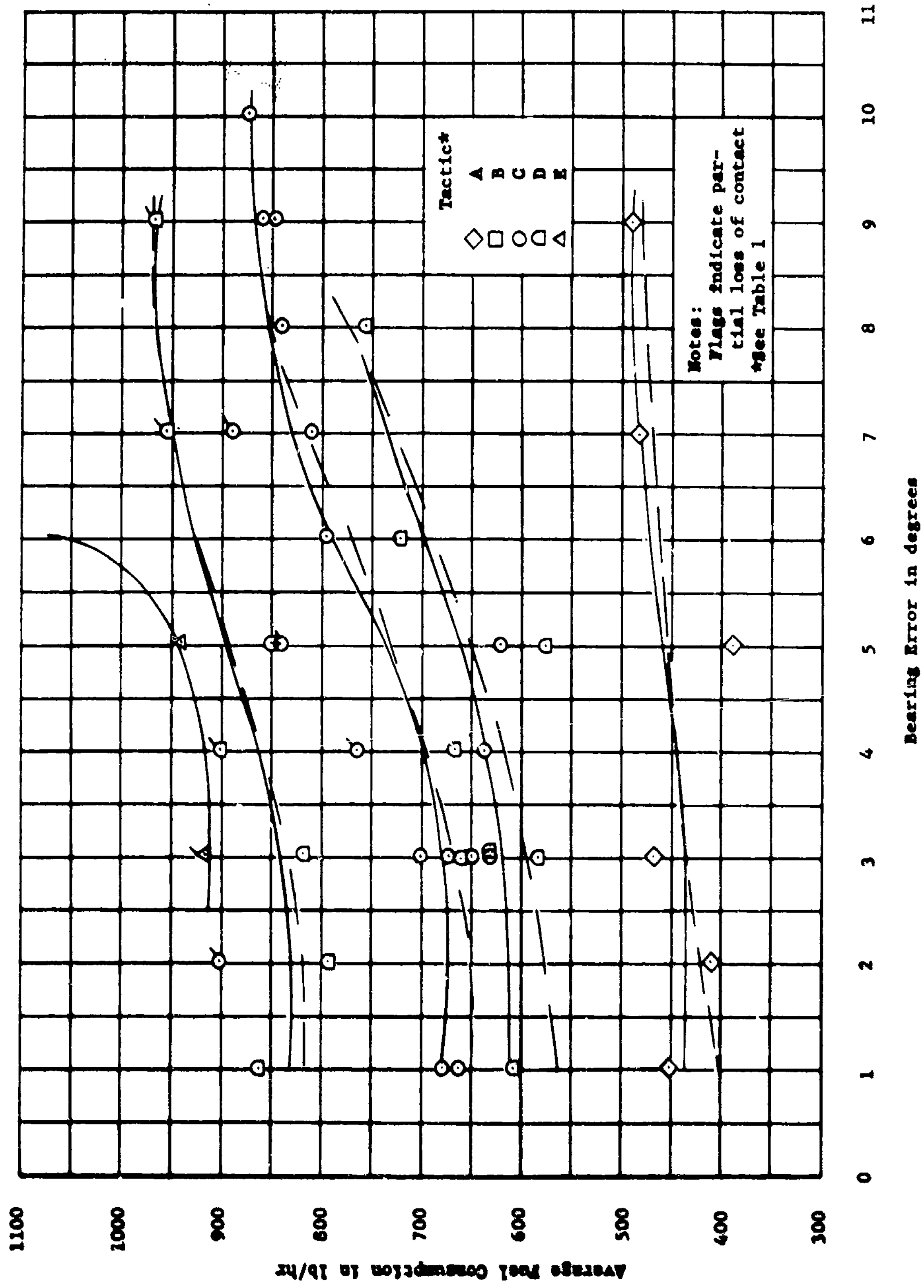

Figure 3 - VTOL Fuel Consumption for Five Submarine Tactics.
(Each point represents 130 hours of simulation.)

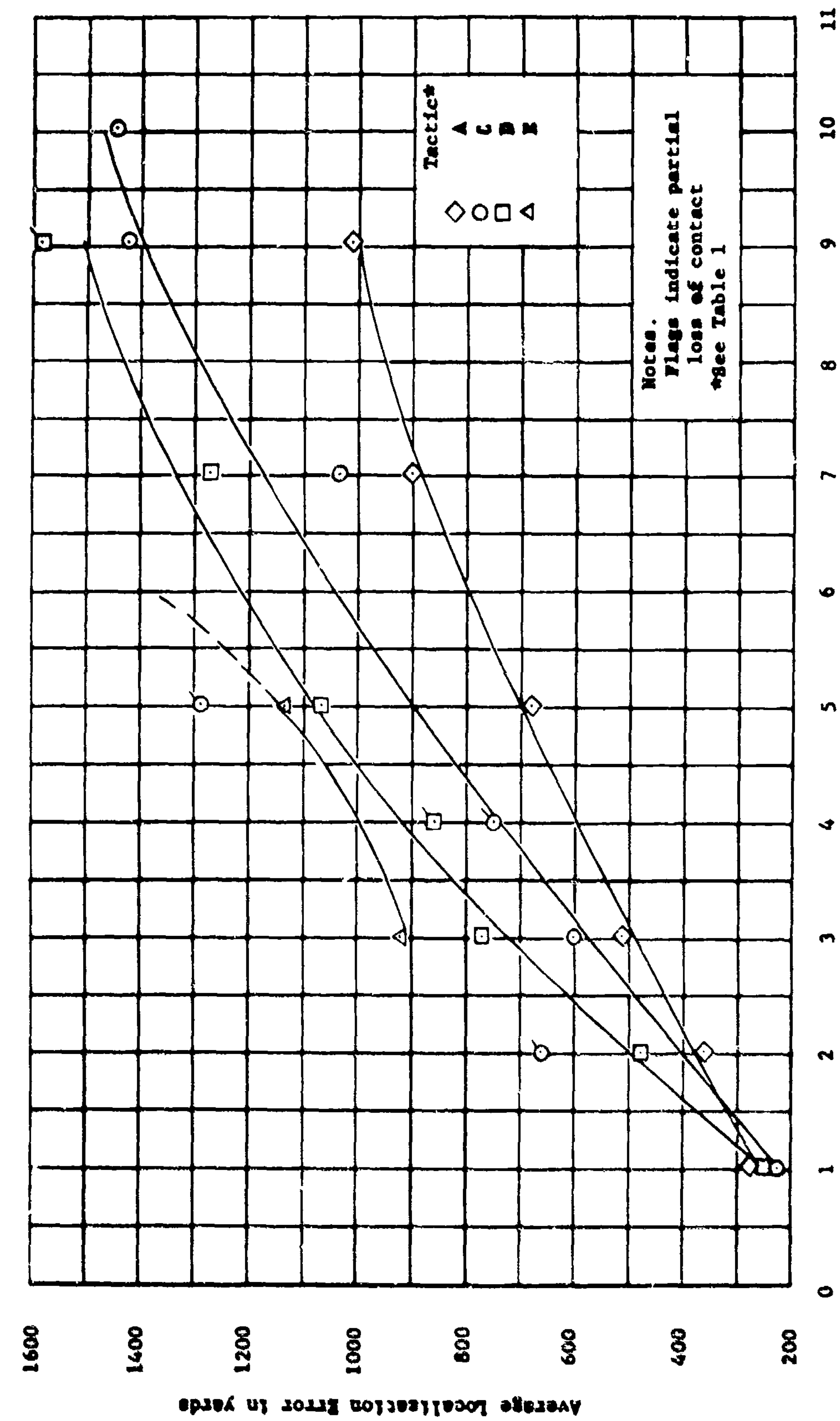

Figure 4 - Average Error in Estimation of Target Position

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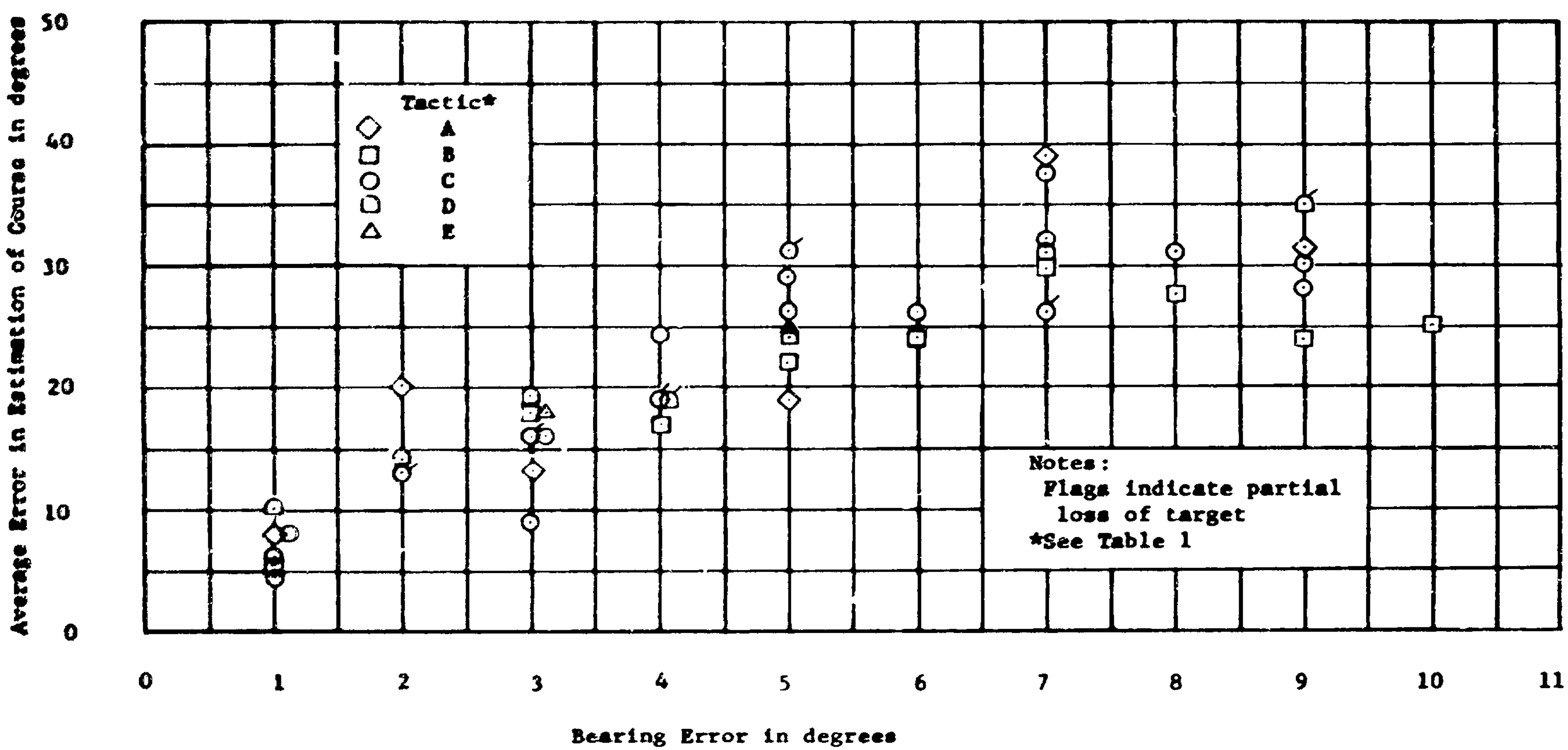

Figure 5 - Average Error in Estimation of Target Course

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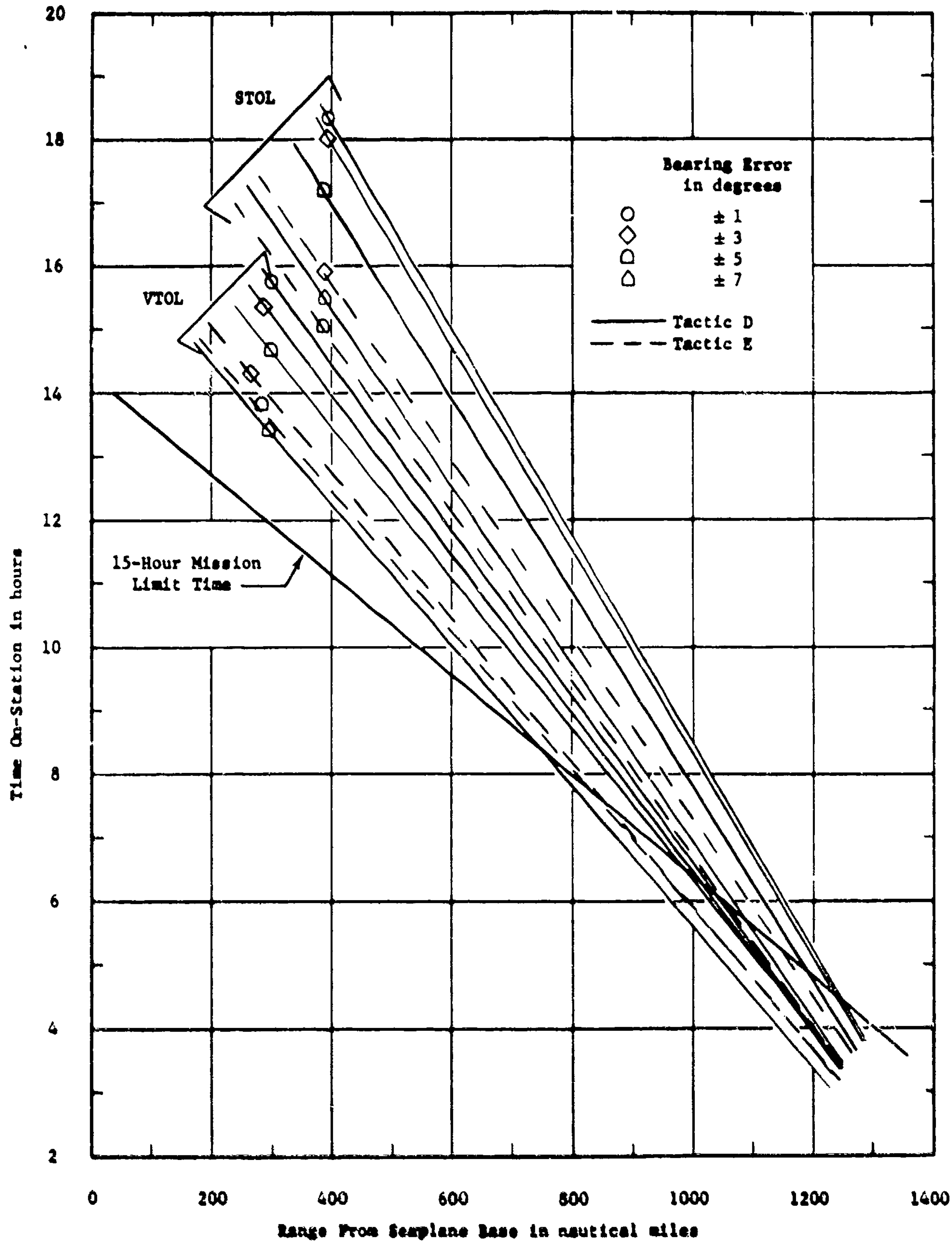

Figure 6 - Seaplane Tracking Time for Two Most Difficult Maneuvers

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4. DESCRIPTIVE NOTES (*Type of report and inclusive dates*)

Formal Report

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11 SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY Bureau of Naval Weapons Department of the Navy Washington, D. C. 20360

13 ABSTRACT

Results are presented of a computerized simulation of an ASW-V/STOL seaplane design capable of operation in high sea states. This study was made to evaluate the effectiveness of a technique utilizing a passive Air Transportable Sonar Surveillance System (ATSSS) with various bearing errors (accuracies) in the performance of the contact maintenance (tracking) mission. The results indicate the tradeoff permitted in bearing error versus fuel consumption and tracking performance using the ATSSS, and also demonstrate the advantages of an integrated ATSSS-disposable sonobuoy technique. The incorporation of a variable-length mission which is a function of submarine tactic and sea state is also considered. (U)

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Security Classification

14 KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Seaplane						
V/STOL						
Tilt-Wing Free-Propeller						
Performance Prediction						
ASW – Target Tracking						
Bearing Error						
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